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A multiscale database of soil properties for regional environmental quality modeling in the western United States

G. Feng, B. Sharratt, J. Vaughan, and B. Lamb

Abstract: The USDA Natural Resources Conservation Service State Soil Geographic (STATSGO) database contains general soils information, but data available in STATSGO cannot be readily extracted nor parameterized to support regional environmental quality modeling. As such, each user must individually and repeatedly process data in STATSGO to obtain necessary soil properties. The objective of this study was to develop a comprehensive database, the Western States Soil Database (WSSD) (http://www.lar.wsu.edu/nw-airquest/soils_database.html), for use in modeling regional soil and water resources and environmental quality across eight western states (Washington, Oregon, California, Idaho, Nevada, Utah, Montana, and Wyoming). We aggregated existing soil properties in STATSGO from 19,681 map units of the eight states and estimated soil properties based upon quantitative relationships among existing soil properties. The WSSD comprises 3,910 map units, with each map unit defined by 10 soil layers and each layer characterized by 31 soil properties. The WSSD was gridded to 1 and 12 km (0.62 and 7.44 mi) resolution cells for application to grid-based environmental models. Data from WSSD was tested against USDA Natural Resources Conservation Service field data and indicated satisfactory agreement; for example, the Root Mean Square Error (RMSE) for sand and clay content varied between 4% and 7%. The RMSE appeared to be greatest for organic matter and was as large as 106% of the measured value. The WSSD provides information on soil properties useful for regional-scale modeling.

Key words: air quality—ecology—plant growth modeling—soil database—soil parameters for regional environmental quality—soil processes modeling—STATSGO database—water erosion—Wind Erosion Prediction System (WEPS)—wind erosion—Western States Soil Database (WSSD)

The USDA Natural Resources Conservation Service (NRCS), through the National Cooperative Soil Survey, developed three soil geographic databases that are appropriate for acquiring soil information at the national, regional, and local scales. These relational databases include the National Soil Geographic (NATSGO) database, the State Soil Geographic (STATSGO) database, and the Soil Survey Geographic (SSURGO) database. The NATSGO database is used primarily for appraisal and monitoring of resources at the national scale of 1:5,000,000. The STATSGO database was designed for a regional scale of 1:250,000 across the contiguous United States. The SSURGO database provides finer-resolution information and was designed primarily for managing and inventorying resources at the farm to county scales ranging from 1:12,000 to 1:63,360.

The STATSGO database was released in 1992 and is available on the Internet at http://www.soils.usda.gov/survey/geography/statsgo (USDA 1995). The STATSGO database was designed for regional-scale planning and management. The database is a valuable tool for mapping soil properties, developing inventories of soil resources, and for modeling water and wind erosion. For example, STATSGO data have been used to assess regional soil and water quality (Navulur and Engel 1998; Shirazi et al. 2001a,b), evaluate soil water erodibility across Oregon (Burns et al. 2002), and assess soil wind erosion in Texas (Zobeck et al. 2000). In addition, the STATSGO database has been used to assess regional soil carbon storage (Guo et al. 2006; Homann et al. 1998; Rasmussen 2006). Most importantly, the STATSGO database can provide information on soil physical, chemical, and biological properties that are required for simulating water quality (Navulur and Engel 1998; Wilson et al. 1996), crop growth and soil productivity (Abdulla and Lettenmier 1997; Nizeyimana et al. 2001), hydrology (Keese et al. 2005), ecology (Waltman et al. 2003), and wind erosion (Zobeck et al. 2000).

The STATSGO database has a structural architecture that consists of map units, soil components, soil layers, and soil properties. Soil layers contain information on 28 soil properties, each of which is defined by a maximum and minimum value. STATSGO data are often used in environmental studies and modeling because the availability of soils data often precludes the necessity of taking costly and tedious measurements in the field. For modeling soil processes at the scale of a map unit, the data within the STATSGO database must be preprocessed and aggregated on the basis of maximum and minimum values, soil layers, and soil components. Modeling processes at a scale larger than a map unit would further require aggregating soil properties across map units similar to the approach taken by Shirazi et al. (2001a,b) who aggregated information in the STATSGO database to derive values for 16 soil properties useful for modeling water quality by mapping unit across the northeastern United States.

Some soil properties that affect water and wind erosion are contained within the STATSGO database, but these data are not in a form directly usable by models that simulate water or wind erosion. In addition, the STATSGO database has not been enhanced with soil properties such as aggregate stabil-

Guanglong Feng is a research associate in the Department of Biological Systems Engineering, Washington State University, Pullman, Washington. **Brenton Sharratt** is a soil scientist for the USDA Agricultural Research Service, Pullman, Washington. **Joseph Vaughan** is an assistant research professor and **Brian Lamb** is a regents professor at the Laboratory for Atmosphere Research, Department of Civil & Environmental Engineering, Washington State University, Pullman, Washington.

ity and aggregate size distribution that are normally required for simulating soil erosion. Although the database created by Shirazi et al. (2001a,b) included aggregate geometric mean diameter and standard deviation, they did not consider other soil properties (e.g., maximum and minimum aggregate size, aggregate stability) that affect soil erosion.

Field-scale wind erosion has been simulated using data from the SSURGO database. This database provides information on soil properties suitable for simulating wind erosion at a scale of several hectares. Feng and Sharratt (2007), for example, used the Wind Erosion Prediction System (WEPS) for simulating soil loss and PM10 (particulate matter with an aerodynamic diameter of ≤10 μm [≤0.0004 in]) emissions from Adams County in eastern Washington. Soil parameters required by WEPS were obtained from the SSURGO database. In addition, Zobeck et al. (2000) used the revised wind erosion equation for simulating wind erosion from two counties in Texas. They compared soil loss estimates based upon soil properties obtained from both the SSURGO and STATSGO databases. Although soil loss was lower when soil properties were obtained from the finer-resolution SSURGO database, the STATSGO database provides generalized soil information applicable for regional-scale modeling.

The STATSGO data are not in a format readily usable by grid-based models, which are useful tools for examining environmental processes that vary across space and time, such as emission and transport of atmospheric pollutants. These models, however, require a set of properties that uniquely characterize the soil within each soil layer and grid cell. Therefore, the single value of a soil property at a given depth within one grid cell must represent the several values that characterize the soil mapping units occurring within the grid cell. Since soil layers are assumed to be uniform across all cells in grid-based models, STATSGO data represented by a diversity of soil layers must be interpolated to a set of standard layers. Soil properties in STATSGO cannot be mapped in ArcGIS or used in a grid-based model due to the range in values and diversity of layer thicknesses for different components. In addition, grid-based models typically require that vertical soil profiles be divided into the same layers at each grid point. Therefore, the layer thickness of all components must be normalized for all map units to a set of standard layers. Miller and White (1998) recognize the importance of aggregating data for use in grid-based models; they developed a multilayer database of 11 basic soil properties (CONUS-SOIL) for modeling hydrologic processes at a 1 km (0.62 mi) resolution across the United States.

Readily available soil information is needed at scales that will support regional modeling of environmental quality. This need is acute in the Pacific Northwest United States where air quality is impaired by windblown dust (Feng and Sharratt 2007). The regional air quality model AIRPACT-3 simulates the emission and transport of air pollutants across the eight western states (Washington State University 2009a). AIRPACT-3 is a grid-based model that simulates atmospheric transport processes at a 12 km (7.44 mi) resolution across the eight states. The emission and transport of PM10 (particulate matter ≤10 μm [≤0.0004 in] in diameter) derived from windblown dust, however, is not simulated in AIRPACT-3 due to lack of information on the emission of PM10 within the domain. The WEPS system can simulate PM10 emission from landscapes, but the lack of grid-based soils data required by WEPS precludes simulating the emission of PM10 across the region. Therefore, this study was initiated by the need for a database that contains the diversity of soil information required in wind erosion modeling and that is compatible with grid-based regional air quality models. In addition, we also recognized the need for soil information at scales other than 12 km (7.44 mi) (scale used in AIRPACT-3) and for other soil information (e.g., hydraulic properties) that may be useful in modeling soil erosion. This paper, therefore, describes the development of a comprehensive, multiscale, multistratum soil property database, the Western States Soil Database (WSSD), for use in grid-based environmental quality models across the eight western United States.

Materials and Methods

This section discusses a method for processing information contained in the STATSGO database to generate the necessary soil parameters required by many grid-based environmental models.

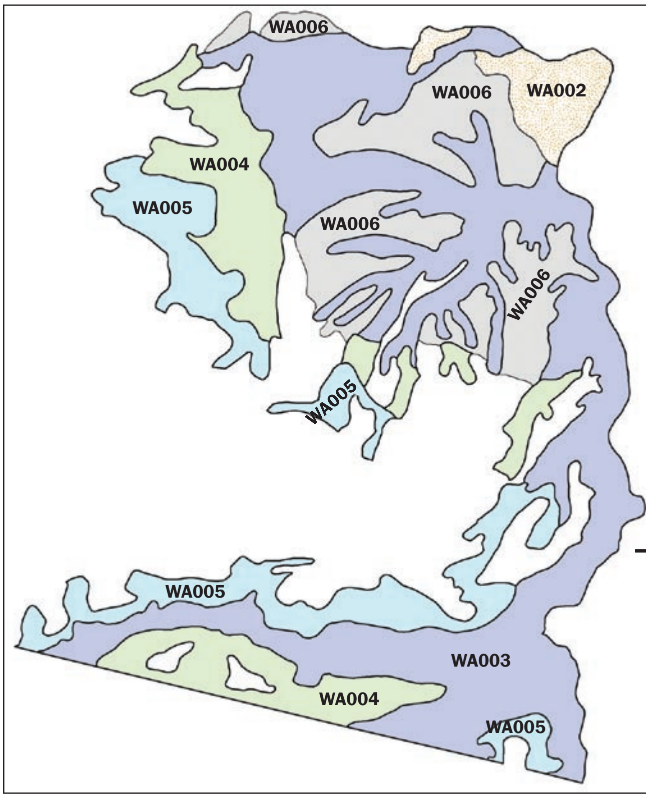
Map units in the STATSGO database are defined as land areas that have similar soil components or soil series. Map unit composition was determined from transects or sampling areas on more detailed maps. Map units have a minimum area of 625 ha (1,544 ac) and a minimum linear dimension of 1.25 km (0.78 mi). The number of map units delineated on each 1 by 2 quadrangle is between 100 and 400 (USDA 1995).

Figure 1 illustrates the architectural structure of the STATSGO database. Each map unit is defined by a composite of no more than 21 soil components. A soil component is a phase of a soil series *(COMPNAME)*, which constitutes a percentage of the total area of the map unit *(COMPPCT)*. Each soil component is defined by attributes or characteristics, such as surface texture and slope. Information in the STATSGO database is organized by hierarchical tables that define map units, soil components, and soil layers. The soil layer table contains information about layer or horizon soil properties, whereas the soil component table contains information about each soil component or pedon or polypedon. Soil properties are defined by a high and low value, which represent the maximum and minimum value of the soil property. Each soil component can have up to six soil layers.

Information contained within the STATSGO database cannot be readily extracted and utilized in simulating soil processes. Data extraction and utilization are hindered as a result of several limitations:

1. The multilayer structure of the database. Each map unit can contain several soil components, and each soil component can be comprised of many soil layers. Simulation of soil processes within a grid cell requires a knowledge of soil characteristics that are representative of the many soil components and map units that comprise a grid cell.
2. Variation in the number, thickness, and depth of soil layers among soil components within the database. Simulation of soil processes requires the determination of soil properties for a set of standardization soil layers across all grid cells.
3. The need to specify a high and low value instead of a single value for each soil property within the database.
4. The lack of information on other soil properties (e.g., saturated hydraulic conductivity, aggregate mean geometric diameter), typically required by soil water and erosion models.
5. The need to define map units as polygons in a vector geographic information sys-

Figure 1
Organization of data within the State Soil Geographic (STATSGO) database.



Component table according to map unit

MUID Map unit	SEQNUM Sequence number*	COMPNAME Component name 1-21 components†	COMPPCT Component percentage‡	60 Attributes Each comp§
WA002	1	CHARD	26	• • •
	• • •	• • •	• • •	• • •
	8	DALLESPORT	4	• • •
WA003	1	LICKSKILLET	22	• • •
	• • •	• • •	• • •	• • •
	10	NANSENE	2	• • •
WA004	1	LAUFER	38	• • •
	• • •	• • •	• • •	• • •
	8	MALLORY	2	• • •
WA005	1	MALLORY	21	• • •
	• • •	• • •	• • •	• • •
	11	ROCKLY	3	• • •
WA006	1	WEISSENFELS	24	• • •
	• • •	• • •	• • •	• • •
	11	SPOFFORD	2	• • •

Layer table according to map unit and soil series phase

MUID Map unit	SEQNUM Sequence number*	LAYERNUM Layer number 1-6 Layers	LAYERDEPL Layer depth low (inch)	LAYERDEPH Layer depth high (inch)	28 Properties
WA002	1	1	0	12	• • •
	1	2	12	27	• • •
	1	3	27	44	• • •
	1	4	44	60	• • •
	2	1	0	5	• • •
	2	2	5	13	• • •
	2	3	13	50	• • •
	2	4	50	60	• • •
	• • •	• • •	• • •	• • •	• • •
WA003	1	1	0	9	• • •
	1	2	9	19	• • •
	1	3	19	23	• • •
	2	1	0	4	• • •
	2	2	4	9	• • •
	2	3	9	22	• • •
	2	4	22	26	• • •
	• • •	• • •	• • •	• • •	• • •
WA004	• • •	• • •	• • •	• • •	• • •

Legend

* Ellipsis in this column represents sequence number between the first and last number.
† Ellipsis in this column represents any component name that should be corresponding to the first column sequence number.
‡ Ellipsis in this column represents the component percentage, which could be any number corresponding to the component in the map unit.
§ Ellipsis in this column represent 60 attributes of each component; it can be expanded to 60 more columns.

tem (GIS) environment. Many regional environmental quality models require information in a uniform grid cell or raster format.

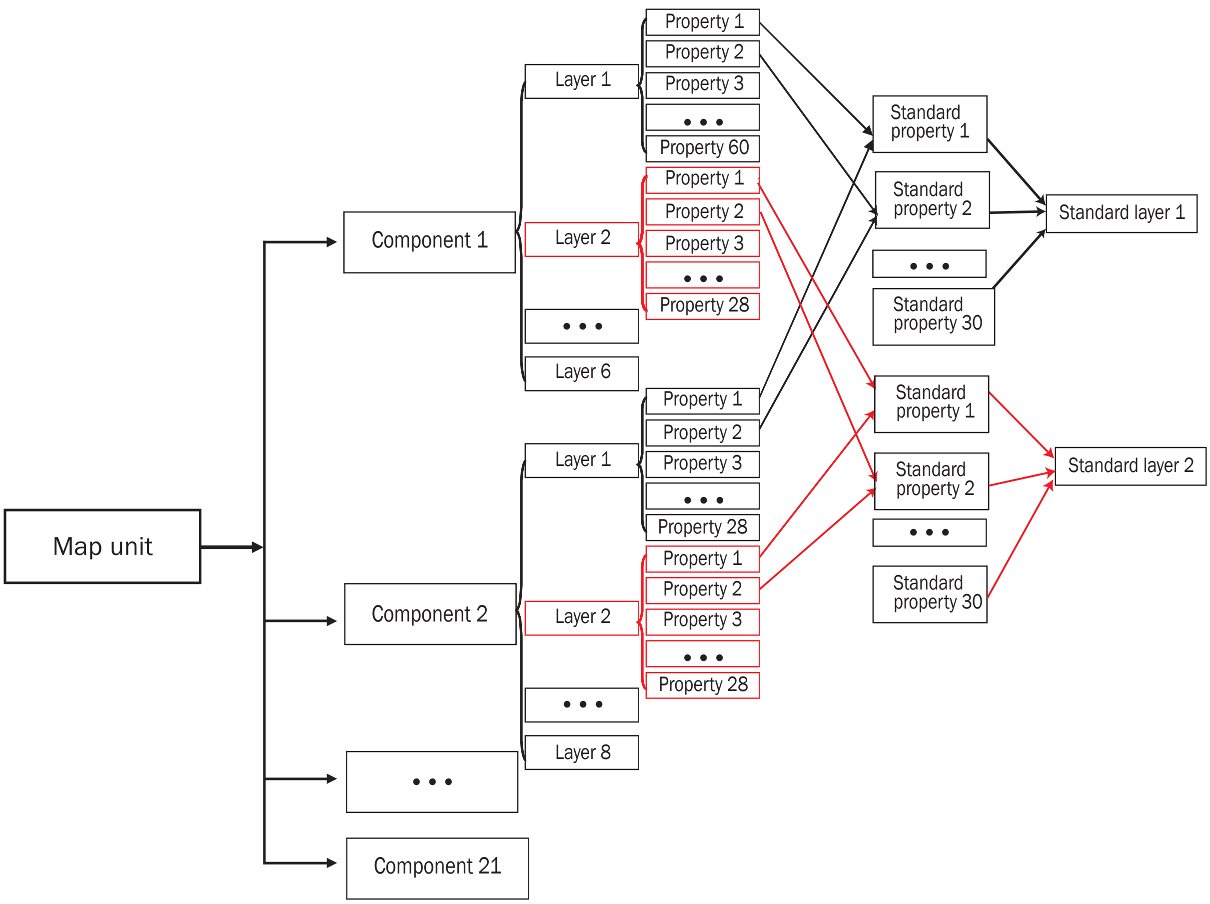
A comprehensive, multilayer, multiscale database containing a broad range of soil properties that influence water and wind erosion was developed for the eight western states. The following section describes the process used to aggregate data and the procedures used to estimate soil properties not contained in the STATSGO database.

Standardization of Soil Layers. Data in STATSGO cannot be easily used in models or to map soil properties in ArcGIS due to the range and diversity of soil layer thicknesses across soil components. In addition, grid-based models typically require soil profiles with uniform layers across each grid point or cell. Therefore, the layer thickness of soil components was normalized for all map units in the WSSD. Data from the STATSGO layer table were interpolated to a set of standard layers. Many models are structured with thinner layers nearer the top of the soil profile. Since over 90% of all soil components in the STATSGO database have an uppermost layer thickness of >5 cm (>1.95 in), the top layer in our soil database was assigned a standard thickness of 10 cm (3.9 in), while all remaining layers in the WSSD were assigned a thickness of 20 cm (7.8 in). In the STATSGO database, few soil components have layers extending below 200 cm (6.5 ft). Therefore, the maximum depth of the soil profile for all map units in the WSSD was 190 cm (6.2 ft), which conforms to the bottom boundary of many vadose zone models.

Aggregation of Soil Properties. Soil components in the STATSGO database were sampled at the midpoint of each layer of a soil profile for obtaining soil parameters for the ten-layer soil profile in the WSSD. In the event that sample depth exceeded the maximum depth of a soil component in the STATSGO database, the value obtained for soil parameters depended upon depth to bedrock. For example, when sample depth was less than the depth of bedrock, the value of soil parameters at the sample depth was assumed to equal the value at maximum

Figure 2

Aggregation of soil properties from layers of different soil components to create a standardized profile for one map unit. The number of layers in the components varied between 1 and 10. For the standardized profile, the number of layers was standardized to 10. A similar process was done for properties. The number of properties per layer varied up to 28, but these properties were aggregated so that each layer had 30.



depth. Likewise, when sample depth was greater than the depth of bedrock, the value of the soil property for that soil component at the sample depth was not included in computing the weighted-average value of the soil property for the map unit. Soil components with shallow profiles were rarely encountered within a map unit. Soil components lacking specific soil property information were excluded when computing the weighted-average value of the soil property. The weighted-average value of soil properties was based upon the soil component percentage (*COMPPCT*) of the map unit.

The component and layer tables in the STATSGO database, as shown in figure 1, were used to obtain physical and chemical properties of layers within a soil profile of a map unit. Since no information is provided about the location of each component within the map unit, physical and chemical properties were aggregated over all components of a map unit using the procedure in figure 2. Aggregate values were determined for both continuous soil properties (properties such as organic matter content that are defined by a sequence of values) and discrete soil properties (properties such as soil texture that are defined by discrete divisions or classes and not by a sequence of values). Values for continuous soil properties were determined by weighting values of each soil component according to *COMPPCT*. Discrete soil properties were determined based upon the largest *COMPPCT* across all soil components within a map unit.

Continuous Soil Properties. Continuous soil properties in our database are listed in table 1. The aggregation procedure, as shown in figure 2, was used to obtain values of soil properties for each layer of every map unit in our database. For example, bulk density (*BD*) was aggregated as follows:

$$BD = \sum_{1}^{n} \left[\frac{1}{2} (BDL_n + BDH_n) \times COMPPCT_n \right], \quad (1)$$

where n refers to the number of soil components of a map unit and *BDL* and *BDH* are the low and high values for the range in bulk density for the soil component in the STATSGO database.

Soil hydraulic properties important for simulating soil processes, but unavailable in the STATSGO database, were estimated utilizing equations in table 2. Saxton et al. (1986) developed equations for soil water potential and hydraulic conductivity based upon readily available soil texture and organic matter information from 1,722 soil samples in the USDA Natural Resources Conservation Service National Soil Characterization database. Saxton and Rawls (2006) later improved these equations to account for the effects of density, gravel, and salinity and formed a comprehensive predictive system (Washington State University 2007). Gijsman et al. (2002)

Table 1
Soil properties in the Western States Soil Database.

Soil property name	Definition
Continuous soil properties	
BD	Bulk density (g cm^{-3})
PORE	Porosity (%)
SAND	Sand content of a soil layer, expressed as a weight percentage
SILT	Silt content of a soil layer, expressed as a weight percentage
CLAY	Clay content of a soil layer, expressed as a weight percentage
No200	Percent by weight of the soil material in a layer or horizon that is less than 3 inches in size and passes a No. 200 sieve (0.075 mm)
No40	Percent by weight of the soil material in a layer or horizon that is less than 3 inches in size and passes a No. 40 sieve (0.425 mm)
No10	Percent by weight of the soil material in a layer or horizon that is less than 3 inches in size and passes a No. 10 sieve (2 mm)
No4	Percent by weight of the soil material in a layer or horizon that is less than 3 inches in size and passes a No. 4 sieve (4.75 mm)
INCH3	Percent by weight of the rock fragments 3 to 10 inches in size in the soil layer
INCH10	Percent by weight of the rock fragments greater than 10 inches in size in the soil layer
SAGd	Soil aggregate density (g cm^{-3})
SAGs	Soil aggregate stability (ln[J kg^{-1}])
AGMD	Soil aggregate geometric mean diameter (mm)
AGSD	Soil aggregate geometric standard deviation (mm)
AMAX	Upper limit of the modified log-normal aggregate size distribution (mm)
PI	Plasticity index for the soil layer or horizon, expressed as percent of moisture by weight.
PWP	Permanent wilting point water content (cm^3 cm^{-3})
FC	Field capacity (cm^3 cm^{-3})
AWC	Available water capacity (cm^3 cm^{-3})
SAT	Saturated soil water content (cm^3 cm^{-3})
KSAT	Saturated hydraulic conductivity (mm h^{-1})
AEP	Air entry potential (kPa)
B	Coefficient of Campbell's equation
OM	Organic matter (g g^{-1})
CEC	Cation exchange capacity (meq $100g^{-1}$)
$CaCO_3$	Carbonate as $CaCO_3$ (%)
pH	The negative logarithm to the base 10, of the hydrogen ion activity in the soil using 1:1 soil:water ratio method (unitless)
Discrete soil properties	
WEG	Wind erodibility group
SURFTEX	Surface soil texture
HYDGRP	The hydraulic group for the soil

compared eight modern methods of estimating soil hydraulic properties and found reliable estimates using methods of Saxton et al. (1986). Therefore, these methods (Saxton and Rawls 2006) were used to estimate soil hydraulic properties in the WSSD (table 2).

Other soil properties important for simulating soil processes, but unavailable in the STATSGO database, were estimated based upon relationships with known soil properties. Porosity *(PORE)* is a measure of the volume of air-filled and water-filled pores in the soil and can be calculated from *BD* and particle density *(PD)* according to

$$PORE = 1 - (BD/PD), \tag{2}$$

where *PD* was assumed to be 2.65 g cm^{-3} (0.096 lb in^{-3}) (Hillel 1980). The *BD* values determined from equation 1 were used to calculate porosity. Soil aggregate density *(SAGd)* can affect both water and wind erosion as a result of scouring and abrasion and can be estimated from soil bulk density and organic matter content (Rawls 1983) according to

$$SAGd = \frac{100}{\left[\frac{(OM \times 100)}{0.224} + \left(\frac{100 + OM \times 100}{MBD}\right)\right]}, \tag{3}$$

where *SAGd* is in g cm^{-3}, *OM* is organic matter content (g g^{-1}), and *MBD* is mineral bulk density without organic matter (equivalent to *BD* if *OM* is <10%). Soil aggregate stability *(SAGs)* is also an important factor affecting abrasion and degradation. The following equation (Skidmore and Layton 1992) was used to estimate *SAGs* based upon the clay content fraction (SF_{clay}), which is the fraction of clay in a soil:

$$SAGs = 0.83 + 15.7 \times SF_{clay} - 23.8 \times SF^2_{clay}, \tag{4}$$

where *SAGs* is expressed as the mean of natural log aggregate crushing energies (ln[J kg^{-1})]). Soil aggregate size distribution influences soil erodibility and is characterized by four parameters, namely aggregate geometric mean diameter (*AGMD* [mm]), aggregate geometric standard deviation (*AGSD* [dimensionless]), maximum aggregate size (*AMAX* [mm]), and minimum aggregate size (*AMIN* [mm]). These parameters were estimated using the following equations (USDA ARS 2007):

$$AGMD = \exp(1.343 - 2.235 \times SF_{sand} - 1.226 \times SF_{silt} - 0.0238 \times SF_{sand} / SF^3_{clay} + 33.6 \times OM + 6.85 \times CaCO_3) \times (1.0 + 0.006 \times Layer\ depth), \tag{5}$$

$$AGSD = 1.0/(0.0203 + 0.00193 \times AGMD + 0.074 / AGMD^{0.5}), \tag{6}$$

$$AMAX = AGSD \times AGMD + 0.84^{(1.52 \times AGSD^{-0.449})}, \tag{7}$$

Table 2

Equations used to estimate soil hydraulic properties (Saxton and Rawls 2006) in the Western States Soil Database.

Equation	Symbol definition
$PWP = \theta_{1500t} + (0.14 \times \theta_{1500t} - 0.02)$	θ_{1500t} = 1,500 kPa moisture (%v)
$\theta_{1500t} = -0.024\ S + 0.487\ C + 0.006\ OM + 0.005\ (S \times OM) -$	S = Sand (%w)
$0.013\ (C \times OM) + 0.068\ (S \times C) + 0.031$	C = Clay (%w)
	OM = Organic Matter (%w)
$FC = \theta_{33t} + [1.283(\theta_{33t})^2 - 0.374(\theta_{33t}) - 0.015]$	FC = Field capacity
$\theta_{33t} = -0.251\ S + 0.195\ C + 0.011\ OM + 0.006\ (S \times OM) -$	θ_{33t} = 33 kPa moisture (%v)
$0.027\ (C \times OM) + 0.452\ (S \times C) + 0.299$	
$AEP = \psi_{et} + (0.02\psi_{et}^{2} - 0.113\psi_{et} - 0.70)$	ψ_{et} = Tension at air entry (kPa)
$\psi_{et} = -21.67\ S - 27.93\ C - 81.97\ \theta_{s-33} + 71.12\ (S \times \theta_{s-33}) +$	θ_{s-33} = SAT-33 kPa moisture (%v)
$8.29\ (C \times \theta_{s-33}) + 14.05\ (S \times C) + 27.16$	
$SAT = \theta_{33} + \theta_{(s-33)} - 0.097\ S + 0.043$	SAT = Saturated moisture at 0 kPa (%v)
$B = -2 \times AEP + 0.2 \times ASGD$	B = Campbell pore size distribution parameter
$KSAT = 1930\ (SAT - \theta_{33})^{(3-\lambda)}$	θ_{33} = moisture at 33 kPa (%v)
$\lambda = 1 / A$	λ = Slope of logarithmic tension-moisture curve
$A = [\ln(1500) - \ln(33)] / [\ln(\theta_{33}) - \ln(\theta_{1500})]$	A = Coefficient of moisture-tension function

where SF_{sand}, SF_{silt}, and SF_{clay} are soil fraction of sand, silt, and clay, respectively. The minimum aggregate size *(AMIN)* (millimeter or inch) equals 0.01 mm (0.0004 in) (USDA ARS 2007).

Discrete Soil Properties. Discrete soil properties include soil texture, wind erodibility group, and hydraulic soil group (table 1). Discrete soil properties for the 10 standard layers within a grid cell were determined based upon the dominant soil texture, wind erosion group, and hydraulic soil group across all soil map units within the cell.

Most models require information in the form of a continuous distribution of particle sizes rather than textural classification. The STATSGO database contains information on soil texture class and percent clay; based upon texture and percent clay, sand and silt percentages were estimated from the USDA soil texture triangle using the midpoint values of percent sand and silt. The sum of percent clay (from the STATSGO database) and estimated sand and silt percentages did not always equal 100%. In these instances, silt percentage was adjusted such that the total equaled 100%. Percent sand, silt, and clay were interpolated for the 10 standard layers in the WSSD and were aggregated over the components for each map unit.

The STATSGO database classifies soils into eight wind erodibility groups (WEG) with soil loss decreasing in severity from WEG1 to WEG8. The database also provides a soil erodibility index (WEI) where WEI is the value of the potential annual soil loss by wind erosion. Each WEG is assigned a WEI with WEG1 corresponding to a WEI of 560 t ha^{-1} y^{-1} (250 tn ac^{-1} yr^{-1}) and WEG8 corresponding to 0 t ha^{-1} y^{-1}. The WEI is based on the relationship of potential soil erosion to the percentage of dry surface soil aggregates larger than 0.84 mm (0.034 in). The WEG provides guidelines for designing, evaluating, and developing alternative cropping systems for mitigating wind erosion and improving air quality, and it also aids in targeting areas for implementing alternative control strategies and USDA conservation programs. Like other discrete soil properties, the dominant WEG is considered to be representative of all soil components in a map unit and was determined using the discrete aggregation procedure. The WEG values in the WSSD can be geographically related to soil types and other attributes such as land use.

Results and Discussion

Mapping of Aggregated Soil Properties. Map units comprising the WSSD are shown in figure 3. Soil properties of these map units vary with depth (layers) and can be displayed in GIS map format. To illustrate, soil physical (e.g., silt percentage), hydraulic (e.g., saturated hydraulic conductivity, wilting point water content) and chemical properties (e.g., organic matter) for the upper-most layer (0 to 10 cm [0 to 3.9 in] depth) of each map unit in the WSSD are displayed in figures 4 to 7. Notable patterns in soil properties are readily apparent across the eight states. For example, soils with a high silt percentage (figure 4) occur in eastcentral California, central Idaho, northwestern Montana, southeastern Utah, southeastern Washington, and northwestern Wyoming. Likewise, soils in southern California, central Idaho, central Oregon, and southeastern Utah appear to be very permeable (figure 5) and retain little water at the wilting point (figure 6). In addition, soils with little organic matter (figure 7) occurred in southern California, southern Nevada, and southwestern Wyoming.

Test of Aggregated Soil Properties. Aggregating soil properties in the STATSGO database or estimating soil properties from empirical relationships may result in inaccurate representation of soil properties in the WSSD. Therefore, to assess the accuracy of the WSSD, we compared soil properties in the WSSD with soil properties measured at discrete locations across the eight western states. The USDA NRCS Soil Survey Laboratory provides nationwide soil survey characterization data (USDA NRCS Soil Survey Staff 2009) on basic soil physical, hydraulic, and chemical characteristics, such as soil texture, bulk density *(BD)*, wilting point water content *(PWP)* and organic matter *(OM)*. These data were measured with standard laboratory procedures (USDA Soil Conservation Service 1982) and had been reviewed and approved for consistency and accuracy. Therefore, our test was restricted to these soil properties. We used georeferenced data within the states of Washington, Oregon, Idaho, California, Montana, Wyoming, Nevada, and Utah to test data in the WSSD. As shown in figure 3, three to four sites in these eight states were randomly selected for the test. At each site, all soil properties in the USDA NRCS Soil Survey Laboratory database were compared with soil properties in the WSSD.

Figure 3
Multiple colors illustrate the complexity of soil map units across the Western States Soil Database (WSSD). The locations of test sites are also shown.

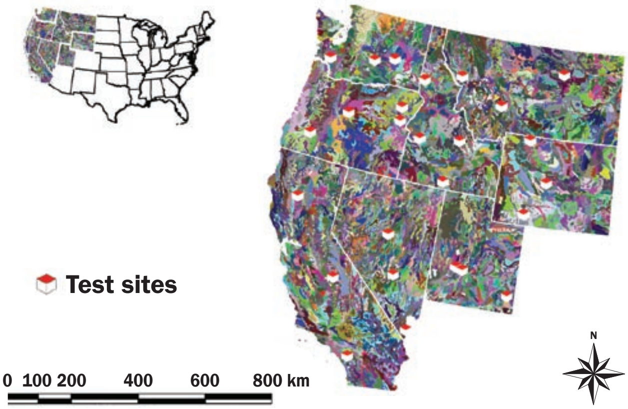


Figure 6
Wilting point water content of the uppermost 10 cm soil layer in the Western States Soil Database.

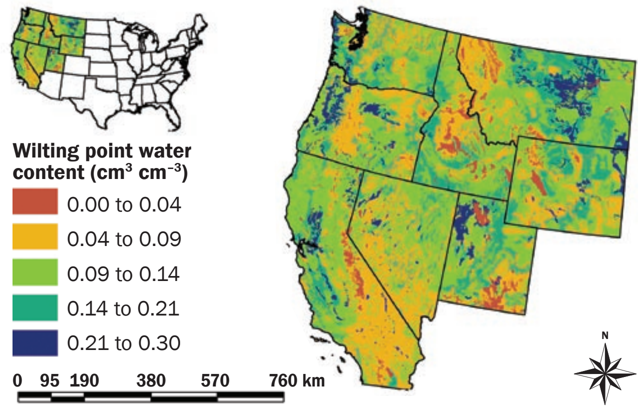


Figure 4
Silt percentage in the uppermost 10 cm soil layer in the Western States Soil Database for the eight western states.

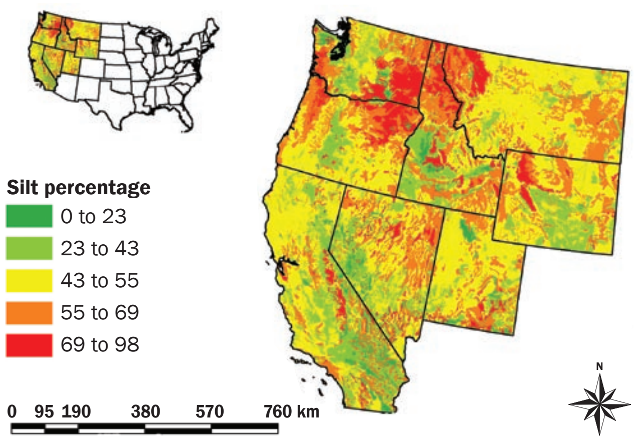


Figure 7
Organic matter content within the uppermost 10 cm soil layer of the Western States Soil Database for the eight western states.

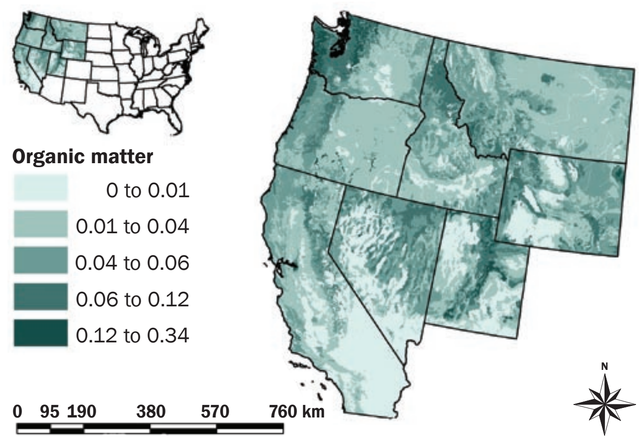


Figure 5
Saturated soil hydraulic conductivity for the uppermost 10 cm soil layer in the Western States Soil Database for the eight western states.

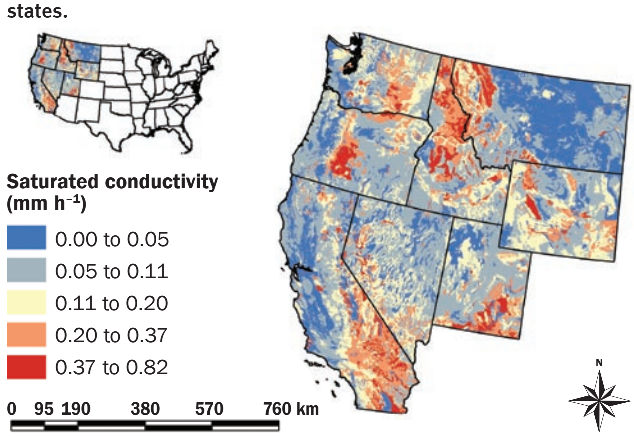


Figure 8
Mosaic of soil map units gridded at a 12 km scale across the Pacific Northwest domain.

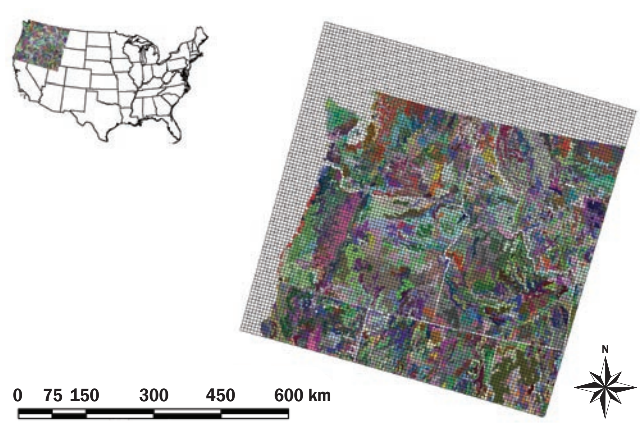


Table 3a

Comparison of soil properties in the upper 10 cm of the profile as obtained from the Western States Soil Database (WSSD) and the USDA Natural Resources Conservation Service (NRCS) soil survey database.

State, County	Lab Pedon*	SAND (%)		CLAY (%)		BD ($g\ cm^{-3}$)		PWP ($cm^3\ cm^{-3}$)		FC ($cm^3\ cm^{-3}$)		OM ($g\ g^{-1}$)		pH	
		WSSD†	NRCS‡	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS
WA, Adams	92P0079	42.65	43.40	15.05	7.40	1.45	1.36	0.11	0.05	0.22	0.25	3.74	0.93		
WA, Kittitas	83P0872	20.00	24.30	13.84	14.30			0.11	0.10			2.43	1.29	7.26	6.80
WA, Lewis	72C0074	20.00	16.20	20.08	20.40	1.37	1.12	0.13	0.14	0.31	0.30	3.22	3.14	6.90	5.60
OR, Baker	85P0835	40.91	36.70	19.53	18.00			0.13	0.07			3.00	4.66	6.61	7.00
OR, Crook	40A0904	61.90	63.80	11.42	12.70			0.10	0.08			3.00	0.54	5.91	7.40
OR, Douglas	40A0860	42.00	39.60	18.79	21.10			0.12	0.19			3.80	4.88	5.95	6.30
OR, Union	40A5477	42.00	31.00	19.90	19.80	1.41	1.12	0.13	0.15			6.18	2.93		
ID, Boise	92P0215	21.10	26.30	16.26	18.60			0.11	0.16			3.53	2.86	6.94	6.60
ID, Cluster	88P0017	20.66	25.30	10.53	20.30			0.10	0.12	0.30	0.35	0.85	2.32	7.67	8.00
ID, Latah	93P0585	20.00	20.60	16.99	18.80			0.11	0.14			3.09	3.08	8.08	5.80
ID, Twin Falls	04N1110	39.80	38.30	18.41	16.00	1.42	0.91	0.12	0.18	0.27	0.38			7.01	6.20
CA, Fresno	84P0458	45.90	51.60	20.63	19.60	1.41	1.65	0.13	0.11	0.26	0.17	2.86	0.94	6.43	5.70
CA, Riverside	40A5434	20.00	22.90	21.50	27.10	1.36	1.55	0.13	0.15	0.30	0.22	4.00	1.85	6.70	7.80
CA, Tehama	90P0220	45.38	44.00	19.74	17.00	1.42	1.65	0.12	0.08	0.25	0.17	1.64	0.86	6.35	5.40
MT, Broadwater	40A3701	39.00	39.70	23.55	19.10	1.38	1.52	0.14	0.11	0.28	0.19	3.47	1.13	7.19	7.90
MT, Missoula	40A3320	32.04	30.90	17.51	12.40	1.41	1.60	0.12	0.05			1.97	1.08	7.82	5.90
MT, Phillips	90P1093	41.60	51.12	20.95	19.20	1.40	1.43	0.13	0.19	0.27	0.22	3.80	2.74	6.99	6.80
WY, Fremont	82P0678	71.35	71.35	8.13	9.45	1.60	1.64	0.08	0.10	0.19	0.17	1.74	0.73	7.44	7.00
WY, Park	92P1092	49.22	49.22	16.69	14.90	1.45	1.13	0.12	0.10	0.25	0.26	2.21	1.81	7.44	7.30
WY, Sweetwater	40A1133	54.10	54.72	14.07	15.54	1.49	1.41	0.11	0.08	0.24	0.22	1.95	1.81	7.17	7.80
NV, Clark	73C0112	81.50	79.40	5.25	3.90	1.68	1.41	0.07	0.03	0.16	0.21	0.28	0.23	7.70	8.30
NV, Lander	82P0324	64.00	66.10	14.84	9.90	1.50	1.41	0.11	0.09	0.21	0.14	3.63	1.14	5.99	7.30
NV, Nye	73C0047	71.94	72.50	6.39	3.78			0.08	0.04			4.81	0.33	6.08	8.50
UT, Millard	85P0938	54.45	49.30	13.60	14.90	1.49	1.50	0.11	0.09	0.23	0.25	1.00	1.54	7.89	8.10
UT, San Juan	07N0493	34.70	45.50	15.21	19.40	1.44	1.61	0.10	0.07	0.21	0.21	0.47	0.81	6.57	7.60
UT, Sevier	93P0040	79.64	64.60	5.97	11.50			0.07	0.08			0.29	0.95	7.95	7.70
Mean		44.46	44.55	15.57	15.58	1.45	1.41	0.11	0.11	0.25	0.23	2.68	1.78	7.00	7.03
RMSE		5.36		3.71		0.21		0.04		0.06		1.51		1.06	

Notes: WA = Washington. OR = Oregon. ID = Idaho. CA = California. MT = Montana. WY = Wyoming. NV = Nevada. UT = Utah. RMSE = root mean square error.
* Pedon identification from the USDA NRCS soil survey database found at http://ssldata.nrcs.usda.gov/datause.asp.
† WSSD is the data from the Western States Soil Database (WSSD).
‡ NRCS is the data from the USDA NRCS soil survey laboratory database.

Table 3b

Comparison of soil properties in the 10 to 30 cm layer of the profile as obtained from the Western States Soil Database (WSSD) and the USDA Natural Resources Conservation Service (NRCS) soil survey database.*

State, County	SAND (%)		CLAY (%)		BD ($g\ cm^{-3}$)		PWP ($cm^3\ cm^{-3}$)		FC ($cm^3\ cm^{-3}$)		OM ($g\ g^{-1}$)		pH	
	WSSD†	NRCS‡	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS
WA, Adams	36.32	45.70	17.40	8.30	1.42	1.37	0.11	0.07	0.23	0.25	0.87	0.72		
WA, Kittitas	20.00	24.30	13.90	14.30			0.11	0.10			2.42	1.29	7.30	6.80
WA, Lewis	18.90	20.10	21.30	16.00	1.36	1.23	0.13	0.12	0.31	0.28	2.92	1.80	7.00	5.50
OR, Baker	33.42	32.10	31.70	37.30			0.18	0.14			1.11	1.39	6.70	6.90
OR, Crook	64.15	63.80	11.60	12.70			0.10	0.08			0.83	0.54	5.70	7.40
OR, Douglas	47.24	38.60	22.00	21.50			0.14	0.17			1.44	1.64	5.70	5.90
OR, Union	38.76	30.00	28.60	20.30	1.35	1.09	0.17	0.15			1.80	2.01		
ID, Boise	21.30	26.30	20.50	18.60			0.13	0.16			2.59	2.86	7.20	6.60
ID, Cluster	20.66	25.30	9.87	20.30			0.10	0.12	0.30	0.35	0.43	2.32	8.30	8.00
ID, Latah	14.70	20.40	20.40	18.80			0.13	0.14			0.94	0.91	8.10	5.80
ID, Twin Falls	35.14	31.00	26.20	20.00			0.15	0.18	0.29	0.28	1.71	0.86	7.00	6.20
CA, Fresno	46.10	47.80	21.50	26.50			0.14	0.14			1.84	0.94	6.50	5.70
CA, Riverside	20.00	19.20	21.50	17.80	1.36	1.54	0.13	0.17	0.30	0.28	0.40	0.78	6.70	7.80
CA, Tehama	43.28	44.10	21.28	24.00	1.40	1.86	0.13	0.07	0.26	0.15	0.47	0.57	6.40	5.80
MT, Broadwater	19.70	39.80	34.83	16.90	1.29	1.44	0.20	0.10	0.36	0.21	0.60	0.60	7.66	8.20
MT, Missoula	31.68	29.93	17.55	16.30	1.41	1.67	0.12	0.06			0.51	0.41	8.04	5.80
MT, Phillips	35.26	34.20	25.63	36.20	1.36	1.43	0.15	0.13	0.30	0.22	2.08	0.86	7.16	7.50
WY, Fremont	72.20	70.10	11.48	14.60	1.55	1.66	0.10	0.10	0.20	0.21	0.84	0.47	8.03	7.30
WY, Park	56.26	50.90	19.18	18.50			0.13	0.11			1.31	1.35	7.48	7.50
WY, Sweetwater	54.20	44.22	19.80	22.25			0.13	0.12			1.16	1.20	7.31	7.80
NV, Clark	81.86	85.10	9.04	3.50			0.08	0.02			0.16	0.07	8.11	8.80
NV, Lander	58.46	58.60	17.36	16.81	1.46	1.39	0.12	0.12	0.23	0.19	0.56	0.79	5.83	7.50
NV, Nye	75.74	68.20	8.33	8.20			0.09	0.05			2.71	0.16	6.03	8.70
UT, Millard	46.40	41.50	24.13	22.60			0.14	0.13			0.26	1.28	7.94	8.10
UT, San Juan	32.09	40.50	19.45	20.90	1.40	1.59	0.11	0.08	0.22	0.22	0.22	0.55	6.69	7.50
UT, Sevier	79.64	70.30	5.97	10.60			0.07	0.08			0.22	0.79	7.80	7.70
Mean	42.44	42.39	19.25	18.61	1.40	1.48	0.13	0.11	0.27	0.24	1.17	1.04	7.11	7.12
RMSE	6.66		5.91		0.19		0.03		0.06		0.82		1.14	

Notes: WA = Washington. OR = Oregon. ID = Idaho. CA = California. MT = Montana. WY = Wyoming. NV = Nevada. UT = Utah. RMSE = root mean square error.
* Pedon identification from the USDA NRCS soil survey database found at http://ssldata.nrcs.usda.gov/datause.asp.
† WSSD is the data from the Western States Soil Database (WSSD).
‡ NRCS is the data from the USDA NRCS soil survey laboratory database.

Table 3c

Comparison of soil properties in the 30 to 50 cm layer of the profile as obtained from the Western States Soil Database (WSSD) and the USDA Natural Resources Conservation Service (NRCS) soil survey database.*

State,	SAND (%)		CLAY (%)		BD (g cm^{-3})		PWP (cm^3 cm^{-3})		FC (cm^3 cm^{-3})		OM (g g^{-1})		pH	
County	WSSD†	NRCS‡	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS
WA, Adams	36.32	37.30	13.60	7.70	1.46	1.42	0.10	0.07	0.22	0.26	0.15	0.38		
WA, Kittitas	20.00	30.30	13.90	12.90			0.11	0.10			1.49	0.91	7.30	7.10
WA, Lewis	18.90	18.60	21.60	18.20	1.36	1.23	0.13	0.12	0.31	0.28	2.81	1.81	7.00	5.60
OR, Baker	31.22	29.90	34.10	30.60			0.19	0.16			1.05	1.22	6.70	6.50
OR, Crook	64.04	63.60	13.00	13.80			0.10	0.10			0.33	0.46	5.90	6.90
OR, Douglas	45.20	35.70	23.70	22.20			0.14	0.18			0.86	1.22	5.60	5.80
OR, Union	35.97	30.00	34.80	20.30			0.20	0.15			1.06	2.01		
ID, Boise	22.40	28.00	22.90	17.00			0.13	0.15			2.05	1.83	7.30	6.50
ID, Cluster	20.66	35.80	9.84	18.70			0.10	0.11			0.43	2.10	8.30	8.00
ID, Latah	14.70	23.00	20.40	16.50			0.12	0.12			0.06	1.10	8.20	5.60
ID, Twin Falls	35.14	35.00	26.00	18.00			0.15	0.15	0.29	0.25	1.42	1.36	7.10	7.70
CA, Fresno	46.53	44.00	21.60	33.40			0.14	0.16			1.74	0.15	6.50	5.30
CA, Riverside	20.00	20.10	21.50	17.80	1.36	1.54	0.13	0.16	0.30	0.28	4.00	0.59	6.70	8.10
CA, Tehama	46.49	43.30	20.90	22.20	1.41	1.86	0.13	0.11	0.25	0.17	0.30	0.36	6.30	6.70
MT, Broadwater	23.60	15.10	32.78	26.00	1.30	1.31	0.19	0.17	0.34	0.39	0.53	0.56	7.72	8.40
MT, Missoula	32.70	28.70	16.43	18.65	1.42	1.74	0.12	0.07			0.51	0.20	8.19	6.00
MT, Phillips	31.74	40.90	30.17	27.90	1.33	1.49	0.17	0.10	0.31	0.20	0.92	0.50	7.30	7.70
WY, Fremont	72.45	69.80	11.70	14.20	1.55	1.66	0.10	0.09	0.20	0.16	0.68	0.32	8.07	8.00
WY, Park	50.69	51.62	20.44	17.30			0.13	0.10			0.80	1.11	7.58	8.10
WY, Sweetwater	49.40	44.07	23.00	21.90			0.14	0.14	0.26	0.29	0.86	0.80	7.53	8.00
NV, Clark	83.72	87.90	8.61	4.10			0.08	0.02			0.14	0.06	8.11	8.80
NV, Lander	50.50	52.85	19.29	19.70	1.43	1.43	0.13	0.13	0.25	0.25			5.79	7.40
NV, Nye	76.04	75.80	9.67	7.78			0.09	0.05			1.35	0.17	6.07	8.70
UT, Millard	46.40	50.84	23.30	22.00			0.14	0.12			0.26	0.87	8.05	8.10
UT, San Juan	36.83	36.30	20.23	24.80	1.40	1.57	0.11	0.09	0.21	0.17	0.19	0.32	6.72	8.30
UT, Sevier	79.64	70.30	6.74	10.60			0.07	0.08			0.22	0.79	7.91	8.10
Mean	41.97	42.26	20.01	18.62	1.40	1.53	0.13	0.12	0.27	0.25	0.97	0.85	7.16	7.31
RMSE	5.94		5.21		0.16		0.03		0.10		0.90		1.16	

Notes: WA = Washington. OR = Oregon. ID = Idaho. CA = California. MT = Montana. WY = Wyoming. NV = Nevada. UT = Utah. RMSE = root mean square error.
* Pedon identification from the USDA NRCS soil survey database found at http://ssldata.nrcs.usda.gov/datause.asp.
† WSSD is the data from the Western States Soil Database (WSSD).
‡ NRCS is the data from the USDA NRCS soil survey laboratory database.

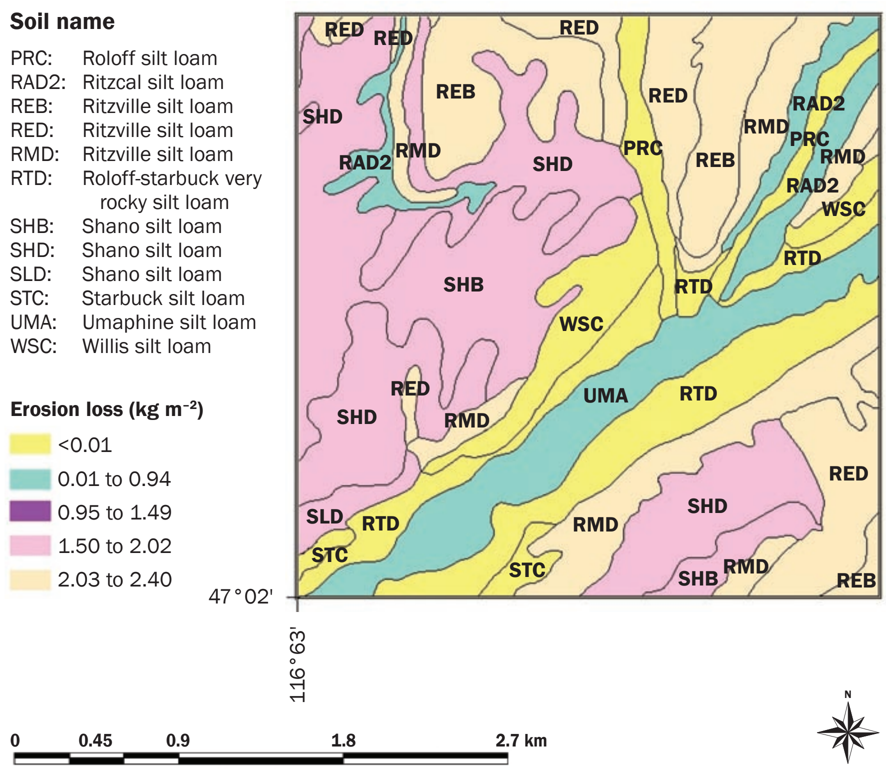
Table 3d

Comparison of soil properties in the 50 to 70 cm layer of the profile as obtained from the Western States Soil Database (WSSD) and the USDA Natural Resources Conservation Service (NRCS) soil survey database.*

State,	SAND (%)		CLAY (%)		BD (g cm^{-3})		PWP (cm^3 cm^{-3})		FC (cm^3 cm^{-3})		OM (g g^{-1})		pH	
County	WSSD†	NRCS‡	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS	WSSD	NRCS
WA, Adams	36.32	33.90	13.60	6.90	1.46	1.39	0.10	0.07	0.22	0.26	0.15	0.28		
WA, Kittitas	20.10	14.90	14.70	12.90			0.11	0.13			1.44	0.69	7.30	8.20
WA, Lewis	18.64	17.10	25.80	18.20	1.33	1.53	0.15	0.17	0.32	0.30	1.11	0.75	7.10	5.90
OR, Baker														
OR, Crook	63.80	51.40	13.90	17.90			0.11	0.14			0.27	0.46	5.60	7.40
OR, Douglas	44.96	35.70	23.90	13.80			0.15	0.18			0.75	0.61	5.60	5.50
OR, Union	35.97	33.00	34.80	21.10			0.20	0.15			1.06	1.13		
ID, Boise	22.40	28.00	23.20	17.00			0.14	0.15			1.80	1.83	7.40	6.50
ID, Cluster			9.84	12.40			0.10	0.09			0.43	2.34	8.30	8.00
ID, Latah														
ID, Twin Falls					1.36	0.93	0.15	0.17	0.29	0.28	1.42	0.98	7.10	6.20
CA, Fresno	75.19	60.60	18.00	33.40			0.12	0.16					6.40	5.30
CA, Riverside	20.00	21.50	21.50	18.40	1.36	1.48	0.13	0.11	0.30	0.32			6.70	8.50
CA, Tehama	47.23	36.10	20.50	29.80	1.42	1.83	0.13	0.14	0.25	0.23	0.21	0.30	6.30	6.60
MT, Broadwater	30.20	26.80	30.52	20.40	1.33	1.37	0.18	0.13	0.32	0.34	0.30	0.38	7.93	7.90
MT, Missoula	36.44	28.10	16.43	19.50	1.43	1.76	0.11	0.07	0.27		0.51	0.18	8.14	6.10
MT, Phillips	31.74	32.10	30.17	33.00	1.33	1.70	0.17	0.11	0.31	0.17	0.58	0.42	7.49	8.00
WY, Fremont	70.50	70.80	8.85	13.70	1.59	1.75	0.09	0.10	0.20	0.20	0.52	0.29	8.26	8.30
WY, Park	49.78	50.70	19.11	12.60	1.43	1.26	0.13	0.08	0.25	0.28	0.73	0.58	7.67	8.20
WY, Sweetwater	50.95	46.90	11.85	18.20	1.51	1.65	0.10	0.10	0.24		0.61	0.14	8.12	8.10
NV, Clark	86.95	89.93	6.79	3.96	1.66	1.57	0.07	0.03	0.15	0.09			8.16	8.80
NV, Lander	39.88	41.20	30.28	34.20	1.35	1.37	0.17	0.16	0.30	0.34			5.52	7.50
NV, Nye	75.50	75.80	11.08	7.50			0.10	0.05			0.15	0.17	6.08	9.50
UT, Millard	50.60	60.60	23.53	9.90	1.40	1.52	0.14	0.08	0.26	0.20	0.11	0.30	8.45	8.50
UT, San Juan	42.09	42.50	18.26	19.10	1.42	1.65	0.11	0.09	0.20	0.16	0.19	0.25	6.72	8.00
UT, Sevier	79.64	80.70	6.74	5.70			0.07	0.05			0.22	0.13	7.88	8.10
Mean	46.77	44.47	18.84	17.37	1.42	1.52	0.13	0.11	0.26	0.24	0.63	0.61	7.19	7.50
RMSE	5.83		7.19		0.21		0.03		0.05		0.51		1.21	

Notes: WA = Washington. OR = Oregon. ID = Idaho. CA = California. MT = Montana. WY = Wyoming. NV = Nevada. UT = Utah. RMSE = root mean square error.
* Pedon identification from the USDA NRCS soil survey database found at http://ssldata.nrcs.usda.gov/datause.asp.
† WSSD is the data from the Western States Soil Database (WSSD).
‡ NRCS is the data from the USDA NRCS soil survey laboratory database.

Figure 9
Illustration of a 12 km resolution cell which contains a number of different soil map units.



Root mean square error (RMSE) was used as a measure of goodness of fit between the estimated soil property value in the WSSD and the measured value in the NRCS Soil Survey Laboratory database. The RMSE was computed as the square root of the mean of the squared difference between estimated and measured values. Comparisons of each soil property were made by soil layers to a depth of 120 cm (3.9 ft); however, only data from the uppermost 10 cm (3.9 in) layer, 10 to 30 cm (3.9 to 11.7 in) layer, 30 to 50 cm (11.7 to 19.5 in) layer, and 50 to 70 cm (19.5 to 27.3 in) layer are listed in table 3. Differences in soil properties between databases were similar across all soil layers. Equations used to estimate other soil properties in the WSSD have been verified by other researchers (Gijsman et al. 2002; Rawls 1983; Saxton and Rawls 2006; Skidmore and Layton 1992), and have been successfully applied to a wide variety of analyses and modeling (Hagen et al. 1995; Saxton and Willey 2005; Saxton and Rawls 2006). Testing could not be performed on all soil properties in table 3 due to lack of measured data at some sites.

Table 3 indicates that the sand percentage across the test sites in Washington, Oregon, Idaho, California, Montana, Wyoming, Nevada, and Utah ranged from 15% to 87%. Thus, testing was carried out across a wide range of soil texture. The value of soil properties in the WSSD is neither consistently higher nor lower than values reported in the USDA NRCS Soil Survey Laboratory database. Across soil layers, the RMSE for percent sand and clay varied between 4% and 7%. In addition, the RMSE for *BD* varied from 0.15 to 0.20 g cm^{-3} (0.007 Ib in^{-3}) (10% to 15% of the measured value) while RMSE for *FC* varied from 0.05 to 0.10 cm^3 cm^{-3} (0.05 to 0.10 in^3 in^{-3}) (20% to 40% of the measured value). The RMSE appeared to be greatest for *OM* (table 3). In fact, the RMSE of *OM* was as large as 106% of the measured value at a depth of 30 to 50 cm (11.7 to 19.5 in). Our method of aggregating appeared to overestimate the measured *OM*. One possible explanation for these larger differences in *OM* is that *OM* varies with time due to changes in land use or management practices (e.g., tillage, crops). Data reported in the USDA NRCS STATSGO and Soil Survey Laboratory databases were not measured at the same time and could account for the large errors in *OM*. Despite aggregating soil properties across soil series within a map unit, values of soil properties in the WSSD are comparable to those found in the USDA NRCS Soil Survey Laboratory database.

Multiscale Database. Models that simulate environmental processes differ with respect to scale of application. For example, WEPS is a process-based model that was designed to simulate wind erosion from agricultural fields (Hagen 1991) whereas AIRPACT was designed to simulate the transport of atmospheric gas and particulates across the Pacific Northwestern United States (Vaughan et al. 2004) and more recently across the western eight United States (AIRPACT-3). An effort is underway to incorporate WEPS into AIRPACT-3 for simulating the emission and transport of windblown dust across the western states (Washington State University Laboratory for Atmospheric Research Areas 2009). However, AIRPACT-3 requires information at a coarser resolution than WEPS. Thus, in order to create a dataset that can be used by grid-based models at different scales across the western United States, we gridded the WSSD to a resolution of 1 and 12 km (0.62 and 7.44 mi) (Washington State University 2009b).

The domain for which the WSSD was created conforms to that used in AIRPACT-3 (all or portions of Washington, Oregon, Idaho, California, Nevada, Utah, Wyoming, and Montana). Each map unit in the WSSD is linked to a grid cell in the domain (all cells are numerically labeled across the eight-state region), and more than one cell may have the same map unit. The WSSD was overlaid on the domain and clipped to obtain the required soils information. Map units across the entire domain were gridded into 1 or 12 km (0.62 or 7.44 mi) cells (figure 8). As illustrated in figure 9, a cell often contains a number of map units, which represent various soil properties. In order to obtain a single value of a soil property for a single grid cell, we calculated the area of each map unit in the grid cell. Continuous soil properties of each map unit were aggregated using an area weighted-average.

Summary and Conclusions

The STATSGO database was used to develop a comprehensive, multiscale, multistratum database of soil properties for environmental quality models. This database contains 31 soil physical, chemical, and hydraulic properties associated with each of 10 layers for 3,910 map units of the eight western states. These properties can provide parameter values required by most hydrology, soil erosion, plant growth, and environmental (soil, water, and air quality) models. Additional parameters, which are not included in the database but are required by some models, can be readily derived based upon the properties provided by the database and quantitative relationships among soil properties as demonstrated in this paper. The WSSD was gridded to 1 and 12 km (0.62 and 7.44 mi) resolution cells for application to grid-based environmental models such as AIRPACT-3. A suite of properties characterizing the soil within each cell is obtained by aggregation of individual soil properties across all soil map units within each cell and weighting values by the area of each map unit within the cell. The database has spatial references. Therefore, all soil properties can be displayed in GIS format. Spatial referencing of soil properties to those found within the USDA NRCS Soil Survey Laboratory database indicates adequate agreement between estimated and measured soil property values. The WSSD is available at http://www.lar.wsu.edu/nw-airquest/soils_database.html.

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References

Abdulla, F.A., and D.P. Lettenmier. 1997. Development of regional parameter estimation equations for a macroscale hydrologic model. Journal of Hydrology 197(1-4):230-257.

Burns, E.R., J. Bolte, R. Hickey, P. Measeles, D.L. Walker, and R. Jaindl. 2002. Development of a statewide erosion vulnerability screening tool for Oregon. Agriculture and Water Quality in the Pacific Northwest. *In* Conference on Agriculture and Water Quality in the Pacific Northwest, Yakima, WA (USA), November 18-20, 2002.

Feng, G., and B. Sharratt. 2007. Scaling from field to region for wind erosion prediction using WEPS and GIS. Journal of Soil and Water Conservation 62(5):321-328.

Gijsman, A.J., S.S. Jagtap, and J.W. Jones. 2002. Wading through a swamp of complete confusion: How to choose a method for estimating soil water retention parameters for crop models. European Journal of Agronomy 18(1-2):75-105.

Guo, Y., P. Gong, R. Amundson, and Q. Yu. 2006. Analysis of factors controlling soil carbon in the conterminous United States. Soil Science Society of America Journal 70(2):601-612.

Hagen, L.J. 1991. A wind erosion prediction system to meet user needs. Journal of Soil and Water Conservation 46(2):106-111.

Hagen, L.J., L.E. Wagner, J. Tatarko, E.L. Skidmore, A.A. Durar, L.J. Steiner, H.H. Schomberg, A. Retta, D.V. Armbrust, T.M. Zobeck, P.W. Unger, D. Ding, and I. Elminyawi. 1995. Wind erosion prediction system: Technical description. *In* Proceeding of WEPP/WEPS Symposium, August 9-11, 1995, Des Moines, IA. Ankeny, IA: Soil and Water Conservation Society.

Hillel, D. 1980. Fundamentals of Soil Physics. New York: Academic Press.

Homann, P.S., P. Sollins, M. Fiorella, T. Thorson, and J.S. Kern. 1998. Regional soil organic carbon storage estimates for western Oregon by multiple approaches. Soil Science Society of America Journal 62(3):789-796.

Keese, K.E., B.R. Scanlon, and R.C. Reedy. 2005. Assessing controls on diffuse groundwater recharge using unsaturated flow modeling. Water Resources Research 41(6):W06010.

Miller, A.M., and R.A. White. 1998. A conterminous United States multilayer soil characteristics database for regional climate and hydrology modeling. Earth Interactions 2(1):1-26.

Navulur, K.C.S., and B.A. Engel. 1998. Groundwater vulnerability assessment to non-point source nitrate pollution on a regional scale using GIS. Transactions of the American Society of Agricultural Engineers 41(6):1671-1678.

Nizeyimana, E.L., G.W. Petersen, M.L. Imhoff, H.R. Sinclair, S.W. Waltman, D.S. Reed-Margetan, E.R. Levine, and J.M. Russo. 2001. Assessing the impact of land conversion to urban use on soils with different productivity levels in the USA. Soil Science Society of America Journal 65(2):391-402.

Rasmussen, C. 2006. Distribution of soil organic and inorganic carbon pools by biome and soil taxa in Arizona. Soil Science Society of America Journal 70(1):256-265.

Rawls, W.J. 1983. Estimating soil bulk density from particle size analyses and organic matter. Soil Science 135(2):123-125.

Saxton, K.E., W.J. Rawls, J.S. Romberger, and R.I. Papendick. 1986. Estimating Generalized Soil-water Characteristics from Texture. Transactions of the American Society of Agricultural Engineers 50(4):1031-1035.

Saxton, K.E., and P.H. Willey. 2005. The SPAW model for agricultural field and pond hydraulic simulation. *In* Mathematical Modeling of Watershed Hydrology, ed. V.P. Singh and D. Frevert. CRC Press.

Saxton, K.E., and W.J. Rawls. 2006. Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Science Society of Agronomy Journal 70(5):1569-1578.

Shirazi, M.A., L. Boersma, C.B. Johnson, and P.K. Haggerty. 2001a. Predicting physical and chemical water properties from relationships with watershed soil characteristics. Journal of Environmental Quality 30(1):112-120.

Shirazi, M.A., L. Boersma, P.K. Haggerty, and C.B. Johnson. 2001b. Spatial extrapolation of soil characteristics using whole-soil particle size distributions. Journal of Environmental Quality 30(1):101-111.

Skidmore, E.L., and J. Layton. 1992. Soil aggregate stability as influenced by selected soil properties. Soil Science Society of America Journal 56(2):557-561.

USDA Soil Conservation Service. 1982. Procedures for collecting soil samples and methods of analysis for soil survey. Soil Survey Investigations Report I, Washington DC.

USDA. 1995. State Soil Geographic (STATSGO) Data Base. Data Use Information. Miscellaneous Publication Number 1492. Fort Worth, TX: Natural Resources Conservation Service (NRCS). http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo.

USDA NRCS (Natural Resources Conservation Service) Soil Survey Staff. 2009. National Soil Survey Characterization Data. Soil Survey Laboratory National Soil Survey Center. USDA NRCS, Lincoln, NE. http://ssldata.nrcs.usda.gov/querypage.asp.

USDA ARS (Agricultural Research Service). 2007. SWEEP: Single-event Wind Erosion Evaluation Program, User Manual. Manhattan, Kansas: Wind Erosion Research Unit.

Vaughan, J., B. Lamb, R. Wilson, C. Bowman, C. Figueroa-Kaminsky, S. Otterson, M. Boyer, C. Mass, M. Albright, J. Koenig, A. Collingwood, M. Gilroy, and N. Maykut. 2004. A Numerical Daily Air Quality Forecast System for the Pacific Northwest. Bulletin of the American Meteorological Society 85(4):549-561.

Waltman, W.J., S.W. Waltman, and M.A. Palecki. 2003. A GIS-based Spatial Pattern Analysis Model for eco-region mapping and characterization. International Journal of Geographical Information Science 17(5):445-462.

Washington State University. 2007. Soil Water Characteristics Hydraulic Propoerties Calculator. http://hydrolab.arsusda.gov/soilwater/Index.htm.

Washington State University. 2009a. Air Quality Forcasting for the Pacific Northwest. Introduction to AIRPACT. http://lar.wsu.edu/airpact-3/introduction.html.

Washington State University. 2009b. Northwest International Air Quality Environmental Science and Technology Consortium. http://www.lar.wsu.edu/nw-airquest/soils_database.html.

Washington State University Laboratory for Atmospheric Research Research Areas. 2009. Agriculture and Air Quality. http://lar.wsu.edu/research/agr-aq.html.

Wilson, J.P., W.P. Inskeep, J.M. Wraith, and R.D. Snyder. 1996. GIS-based solute transport modeling applications: Scale effects of soil and climate data input. Journal of Environmental Quality 25(3):445-453.

Zobeck, T.M., N.C. Parker, S. Haskell, and K. Guoding. 2000. Scaling up from field to region for wind erosion prediction using a field-scale wind erosion model and GIS. Agriculture, Ecosystems & Environment 82:247-259.